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Original Article

DESIGN AND THERMO STRUCTURAL STRESS ANALYSIS OF AXIAL FLOW GAS TURBINE BLISK

SALEEM M [1] & J UDHYAPRAKASH[2]

[1]*Assistant Professor, Department. of Aeronautical Engineering, Veltech Dr. RR & Dr. SR University, Chennai, Tamilnadu, India*

[2]*Assistant Professor, Department. of Mechanical Engineering, Veltech Dr. RR & Dr. SR University, Chennai, Tamilnadu, India*

ABSTRACT

Several challenges to control the vibration in turbine blades. Due to high turbine inlet temperature and vibration has been found in mechanical industries. Blisk or integrally bladed rotor has been used in the compressor engines Applied the thermal and mechanical loads on disk and turbine blades. Inconel 718 and CMSX-4 are the materials, chosen for the disk and the blades of blisk. The thermal analysis is first carried out in patron/ MSC Nastran. Thermal stress and thermo structural analysis is done for the blisk.

OBJECTIVE: The objective is to design an axial flow gas turbine blisk and perform thermo structural analysis of the turbine blisk.

KEYWORDS: Turbine Blades, Inconel 718 and CMSX-4 & turbine blisk.

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INTRODUCTION

The blades of gas turbine are to be fitted carefully to the disk. While considering the blade root of the following aspects are to be considered.

- The root should be able to transmit the centrifugal force and vibrations to the turbine disk.
- It should be easy to mount the blades on the turbine disk.
- The manufacturing process should be affordable.
- The temperature effects of the blades and the disk should not cause expansion due to high temperature and should not lead to any looseness or deformation of the attachment.

Early turbine blades were fitted to the disk, by the delaval root fixing, which was later suppressed by the dove tail attachment and fire tree mechanical attachments, add on to the weight and increases drag. The efficiency may be increase, by removing the mechanical attachment and fixing the blades to the disk by alternate means. : A blisk is a single engine component consisting of a rotor disk and blades, which may be integrally cast, machined from a solid piece of material, or made by welding individual blades to the rotor disk. Blisk may also be known, as integrally bladed rotors (IBR: when the blades and disc are integrally cast, they are subject to different thermal and mechanical loads. In order to overcome this problem, dissimilar materials may be used for the disk and the blades. The blades and disk made of dissimilar materials, can be joined by circular friction welding.

When it comes to vibration, the blisk has a disadvantage in that the complexities that degrade efficiency – mechanical attachments also damp vibrations. When the blade passage frequency, associated with a noble stage matches a blade resonance frequency, the pulsing air flow can induce high blade vibration levels. With inadequate damping, the result is high cycle fatigue and eventual figure.

One way to damp vibrations might be to introduce piezoelectric materials, which can change shape in response to an electrical charge, or generate a charge in response to a change of shape. A piezoelectric element bonded to or embedded in a blade would damp vibration, by converting some of the energy associated with vibration into electrical energy. That energy could then be dissipated in electrical impedance. Manufacturing such a blade, however, would pose several challenges. With piezoelectric elements integrated at key locations, the blade would still have to maintain high aerodynamic efficiency and endure the force of thousands of g's of acceleration. Blades constructed of composite materials could potentially incorporate piezos, while meeting these requirements.

DESIGN CALCULATION

Input Parameters

Table 1: Input Parameters

T_{01}	1200K
T_{03}	970.22K
T_{03}'(s)	935.88K
P_{01}	6.017bar
P_{03}	2.230bar
Mass flow rate	20kg/s
η	0.87

Design Calculation by Formulae

Table 2: Design Calculation by Formulae

Lower limit of rim speed(in ft/s)	440m/s
ῳ	2.275
$\tan\beta_3$	1.426
β_3	54.96
β_2	16.12
α_2	56.98
α_3	10

Specifications of Turbine Blisk

Table 3: Specifications of Turbine Blisk

Chord	35.56mm
Chord to height ratio	0.4
Blade height tip diameter	89mm
Tip diameter	502mm
Hub diameter	422mm
Mean diameter	462mm
Number of blades	27

Airfoil Coordinates at Blade Root

Table 4: Specifications of Turbine Blisk

x(mm)	Y(mm)	Y'(mm)
0	0.9398	0.9398
1.27	0.0508	4.7447
2.54	0.9144	6.8199
5.08	2.4765	9.6012
7.62	3.683	11.2538
10.16	4.5847	12.4968
12.7	5.2324	13.1318
15.24	5.5753	13.2969
17.78	5.7150	13.0683
20.32	5.5880	12.3901
22.86	5.2324	11.2141
22.4	4.6228	9.4996
27.9	3.7338	7.5438
30.48	2.5958	5.4102
33.02	1.2141	3.0734
35.56	0.4826	0.4826

Airfoil Coordinates at Blade Tip

Table 5: Airfoil coordinates at blade tip

x(mm)	Y(mm)	Y'(mm)
0	0.8354	0.8534
1.27	0.1066	3.2816
2.54	1.0066	4.7468
5.08	2.5577	6.6472
7.62	3.5153	7.6682
10.16	4.0259	8.0873
12.7	4.1544	7.9044
15.24	3.8785	7.2237
17.78	3.4086	6.4135
20.32	2.91846	5.16159
22.86	2.4282	4.7726
22.4	1.9177	3.9192
27.9	1.3563	3.0251
30.48	0.7670	2.0878
33.02	0.1701	0.1704
35.56	0.4267	0.4267

Table 6: Specifications

Parameters	Root	Tip
Leading edge radius	0.9525	0.85009
Trailing edge radius	0.4064	0.4064
Stagger angle	10.10	37.5
Blade inlet angle	47.30	18
Blade outlet angle	50.51	54.95

RESULTS AND DISCUSSION

Thermal analysis

The thermal analysis is carried out with half-hot condition, for instance a temperature of 538 deg C is applied on

the nodes along the rim, whereas the bore is exposed to temperature of 260deg C, this forms the worst possible case that can be expected, while the turbine is in operation.

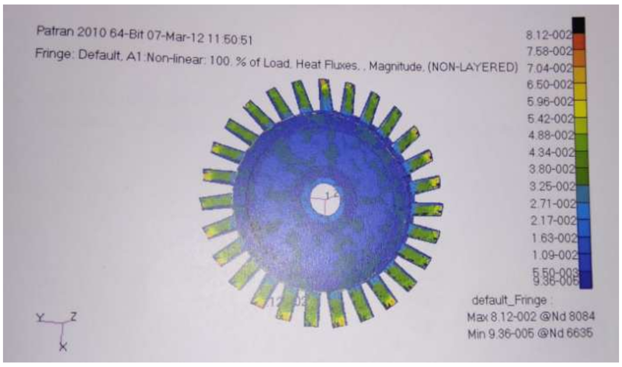

Figure 1: Heat Flux Distribution

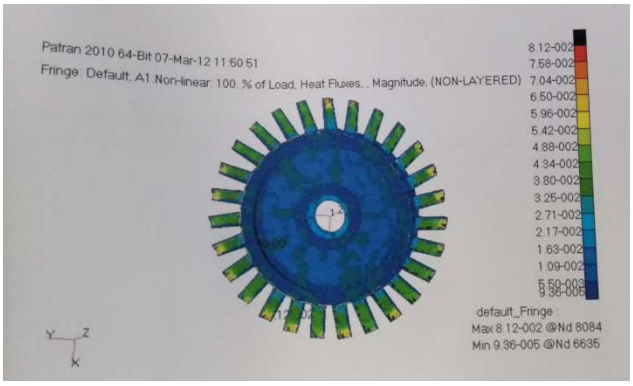

Figure 2 Temperature Distribution

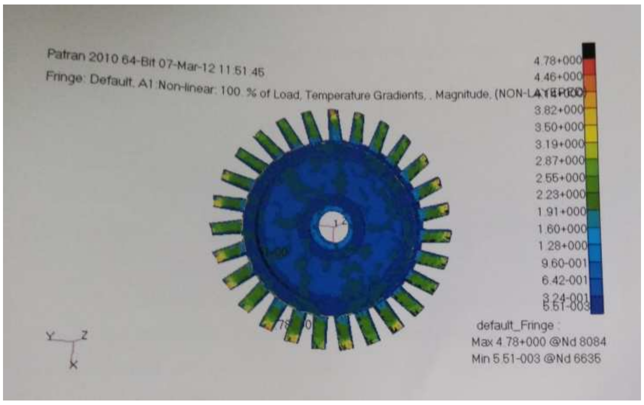

Figure 3: Distribution of Temperature Gradient

Thermo Structural Analysis

The results of the thermal analysis, such as heat flux and temperature gradient are applied are applied as input temperature, or temperature load for the thermo structural analysis. The value of yield stress and ultimate single crystal alloy CMSX-4 is considered as that of the entire model because it is the lower value with that of Inconel 718.

Firstly, thermo structural analysis is carried out on the axial flow gas turbinr blisk, for varying turbine inlet temperatures say 538deg C, 649 deg C, and 760 deg C. Rotational speed is constant 50000 rpm.

Property	Temperature		
	538degC	649 deg C	760 deg C
Von missed stress(max)Pa	762	915	1060
Yield stress Mpa	925	998	1050
Ultimate stress Mpa	985	1070	1175

This variation of von Mises stress, due to the thermal load only is plotted. The von Mises stress due to the centrifugal load only or that due to both thermal and centrifugal load, do not show significant variation when the rotational speed is kept constant.

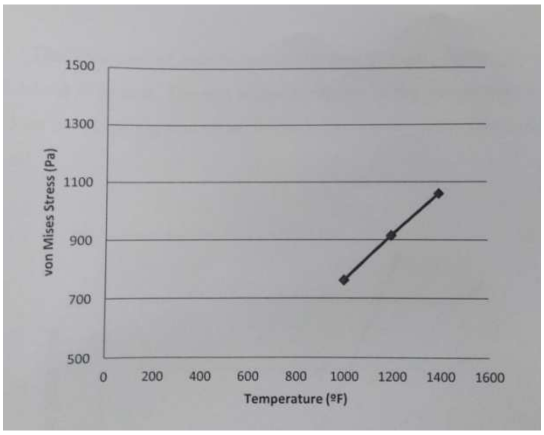

Figure 4: Variation of on Mises Stress with Temperature at Rotational Speed

Secondly, Thermostructural analysis is carried out on the turbine blisk, for varying rotational speeds say 30000rpm, 40000rpm and 50000rpm, but at a constant input temperature of 760 deg C.

Property	Rotational speed		
	30000rpm	40000rpm	50000rpm
Von missed stress(max)Pa	240	426	666
Yield stress Mpa	925	925	925
Ultimate stress Mpa	985	985	985

Figure 5: Von Mises Stress Distribution at 1000f, 5000rp

Figure 6: Von Mises Stress Distribution at 1200f, 5000rpm

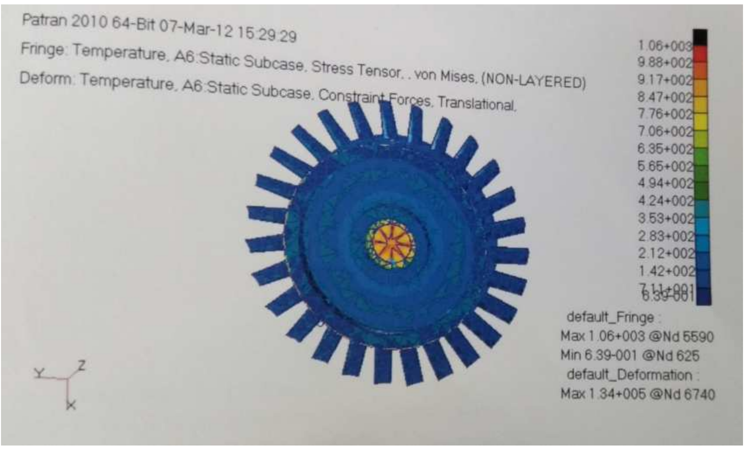

Figure 7: Von Mises Stress Distribution at 1000f, 50000rpm

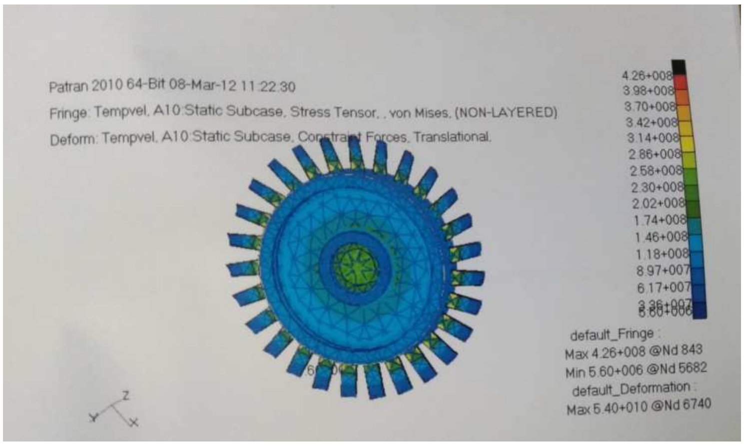

Figure 8: Von Mises Stress Distribution at 1400f, 40000rpm

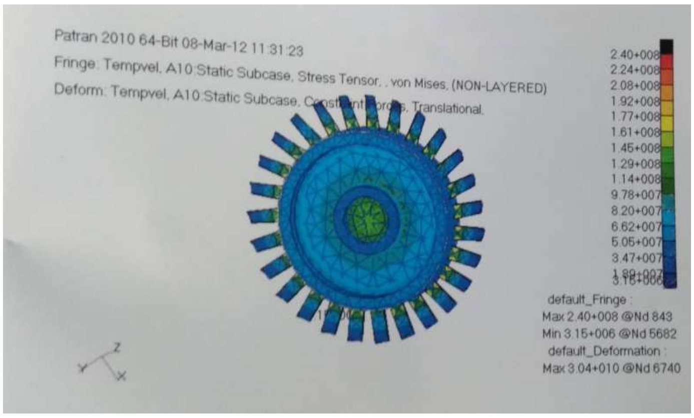

Figure 9: Von Mises Stress Distribution at 1000f, 5000rpm

CONCLUSIONS

The blisk is subjected to very high thermal and mechanical stresses (combined effects of centrifugal force and thermal gradient). Thermo structural analysis is preformed, on the three dimensional model of blisk. From the results of the analysis, the maximum von Mises stress under thermal and centrifugal load, is within the yield strength of both materials , Inconel 718 and CMSX-4 chosen for the disk and blade, respectively. So, the blisk is expected to the FAILURE FREE, WHEN CONSIDERING THE THERMO STRUCTURAL ASPECTS.

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